KNOWLEDGE MANAGEMENT FOR INDUSTRIAL SAFETY, GENERIC RESOURCE PLATFORM COMBINED WITH AN ONTOLOGY BASED APPROACH

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The capacity to manage risks and maintain industrial safety is largely based on the capacity of various actors to acquire, maintain and share knowledge on a large variety of subjects. The actors are, of course, the plant operator but also the employees, the competent authorities, the external maintenance teams or internal or external experts in charge of risk assessment and design of risk management. The knowledge ranges from the regulatory framework to the details of a machine or a process but also includes the general knowledge about industrial safety, the hazardous phenomena, the properties of the substances. Part of this knowledge is also largely tacit. It lies in the brain of the scientific experts or the employees who are able to make the connection between apparently disconnected pieces of knowledge. Detecting, extracting, maintaining and communicating this knowledge are typical knowledge management activities. This is the reason why INERIS has initiated a research program dedicated to knowledge management with several initial outcomes that will be presented in this paper together with the general objectives of the program and the perspectives for the coming years.

The first part of the paper is dedicated to a recall of the knowledge management principles based mainly on the typology of knowledge introduced by Nonaka. It is put in relation with the typology of knowledge used in safety management activities. Two examples of knowledge management systems are presented and related to the typology of knowledge previously described. In both cases, the added value resides in the capacity to establish relations between different knowledge elements. This is partly realised by documents indexing and the use of efficient information retrieval tools. The development of an ontology of industrial safety contributes to achieving these goals. It constitutes a reference for indexing and will offer a structure for future developments of semantic web-based tools. Such an ontology is presently under development. Its use to improve the indexing and information retrieval in the knowledge management systems is illustrated.

KEYWORDS: safety, knowledge management, risk analysis, information system, ontology

INTRODUCTION

Human factor is the cause of up to 80% of industrial accidents [Cacciabue, 2000]. In a recent paper Z. Nivolianitou [Nivolianitou, 2006] analysed the full accident reports in the MARS database and showed that after examination, many causes initially classified as equipment failure were actually due to organisational factors. An examination of accident reports and recommendations in the accident databases shows that in many cases the organisational deficiencies can be formulated in terms of lack of knowledge. A frequent conclusion is that there is a lack of training of operators, but often, it is a more general lack of knowledge of risks or safety issues associated with equipment or substances that caused an insufficient control of the situation. This lack of knowledge is, for example, the lack of preliminary knowledge that would have led to a risk analysis, the lack of risk analysis itself, the lack of communication of safety critical information, the lack of application of hazard lessons learned from similar activities. In her conclusions concerning the petrochemical industry, Z. Nivolianitou considers that there is a lack of proper safety culture to enable effective use of available knowledge for the prevention of major accidents and that there is a lack of a structured communication system to diffuse this knowledge.

This conclusion is used to stress the need of a major accident reporting system to collect and diffuse the knowledge on industrial accidents. However it can also be extended to the need of a more general knowledge management system dedicated to managing the knowledge necessary to deal with industrial risks. This paper is dedicated to presenting some elements of such a system. It introduces the basis of knowledge management, explores the variety of knowledge involved in safety management situations and presents a first structure of a KM system. It then deals with the potential applications of ontologies to improve the KM activities.

WHAT IS KNOWLEDGE MANAGEMENT?

Knowledge Management (KM) refers to a range of practices used by organisations to identify, create, represent, and distribute knowledge for reuse, awareness and learning across the organisation[1].

[1]Definition from Wikipedia, example of a participatory knowledge management system.

MANAGING TACIT AND EXPLICIT KNOWLEDGE

The knowledge can be divided into two main categories: the explicit knowledge and the tacit knowledge [Nonaka 1994]. Explicit knowledge is the knowledge that is conscious and can be documented. Tacit knowledge is the knowledge that resides in the people's mind in a more or less formalised form, most of the time unconsciously. Nonaka identifies the various operations that can be undertaken on knowledge. Transforming the tacit knowledge into explicit knowledge is often called formalisation or externalisation. Making explicit knowledge accessible to people who may benefit from it is diffusion. Making the explicit knowledge turn into tacit knowledge of actors who will then be able to use it is internalisation. A complete knowledge management system should be able to perform all these tasks. It should also be able to deal with generic and specific knowledge.

GENERIC VERSUS SPECIFIC KNOWLEDGE

Beside the traditional tacit versus explicit classification of knowledge the distinction between generic and specific knowledge is essential. Generic knowledge corresponds to the general concepts. Specific corresponds to the instances of these concepts in a given context. Competence is the ability to use generic knowledge in a specific context. Many situations illustrate this need to possess generic knowledge that will be used to extract and interpret specific information or knowledge. Among them, risk analysis is the most emblematic. On the other hand, learning from experience, and especially from past accidents obeys to the opposite process. It is specific knowledge that is used to produce generic information that will be used in other context to interpret specific data.

However, there is a large variety of knowledge management system structures and processes answering to a large variety of needs. Designing a KM system requires following a series of steps that will be described in the next paragraphs.

KNOWLEDGE MANAGEMENT ISSUES IN RELATION WITH INDUSTRIAL SAFETY

The issue of the application of knowledge management to industrial safety is not new. The need for a safety related knowledge management strategy was already stressed in 1996 by F. Lees who wrote "*knowledge of its processes and plants is one of the prime assets of a company, but the management of this asset often appears to be relatively neglected*". Yet, it seems that the link between knowledge management and industrial safety has not been intensively dealt with by researchers in the last decade except for the implementation and exploitation of a learning from accidents system. In the meantime however, knowledge management has become an issue in many companies.

Different factors contribute to the development of knowledge management. Companies are facing an ever more complex world because of the evolution of technologies. They have to react quickly to keep their rank in the economic competition. They must be able to capitalise former experience. At the same time they are facing new threats such as the retirement of generations of experienced workers, the transformations due to fusion and reorganisations of entire economic sectors. All these evolutions are seen as having a potential impact on the economic capacity of the companies. They also can have an impact on safety. Authors such as Rassmussen, Svendung or Leveson have considered the accidents in the light of the socio-technical model of system operation. In such an approach, the information subsystem plays an important role in the development of accidents. Knowledge management at various organisational levels is thus a key among the others to improve safety of industrial activities.

SPECIFYING AND IMPLEMENTING A KNOWLEDGE MANAGEMENT SYSTEM

A first approach of the design of a knowledge management system is user-centred. It focuses on the future users of the system, their needs and the way they will use the system. The users are not only the beneficiary of the formalised knowledge but also the actors owning a tacit or explicit knowledge that will be used as input to the system. The following questions are thus in the heart of the design process:

Who will be the users?
Which are the various user types?
What are their characteristics and behaviours?
What are their goals and tasks?
In which situations and contexts will they operate the system?
What types of knowledge is going to be processed by the system?
What are the tools and organisation already existing?
What is the life cycle of knowledge in the organisation, how is it validated, when and how does it become obsolete?

The users of a safety related Knowledge Management system could be all the actors involved in the industrial safety management at the various stages of an industrial plant: design, building, operation, maintenance, shutdown, decommissioning. Those actors are, authorities, process experts, risk experts, plant designers, plant builders, plant operators, plant workers, plant management staff, contractors. Their needs are different but they all interact with common knowledge elements and should be able to share common representations, to be aware of risks associated with given substances or equipment and to take sound decisions within the organisation.

Examples of knowledge associated with safety of hazardous equipment are given in [Wintle, 2006] where the key competencies required to manage equipment containing hazardous and/or pressurised fluids are listed. This knowledge ranges from very general competencies such as *education and training in technical and mechanical engineering* or *teamwork skills and understanding the roles of others* to very specific knowledge such as *familiarity with the equipment concerned, together with the detail of the* *design and materials of construction, and the operation and maintenance requirements* or *understanding of the relevant regulatory requirements and any approved code of practice and guidance for the equipment.*

This list illustrates the large variety of knowledge involved in safety related processes and the difficulty of setting up a knowledge management system dedicated to safety aspects. In fact an ideal knowledge management system should be able to deal with information, i.e. explicit formalised knowledge, skills, which can be considered as tacit knowledge, and competence which is the ability to operate explicit and tacit knowledge in a given context. Safety culture should also be in the heart of a reflection on safety related knowledge management. Safety culture is the capacity to interpret information and give it a sense in terms of safety. In addition, it is the understanding of safety concepts, safety operations and rules.

TOWARDS THE DEFINITION OF SAFETY CRITICAL KNOWLEDGE

Given this general context, our objective is to define and set up a knowledge management system that would enable the industry to better manage its safety critical knowledge. This objective imposes to define the **Safety Critical Knowledge (SCK)**. In a first approach it could be defined as the knowledge necessary to design, build, operate, maintain and shutdown a system in safe conditions. **SCK** is the knowledge that can, if it fails, lead to an accident or an increase of the accident probability. It includes the knowledge necessary to operate the safety barriers and the emergency procedures. It is also the contextual knowledge necessary to understand the safety management context and proceed to the risk communication operations.

SCK can be identified in various situations at different stages in the life cycle of the plant:

Design: The **SCK** is, for example, the knowledge necessary to identify potential risks of the future plant and design the process, storage and other plant equipment to inherently reduce the risk. It is also the knowledge necessary to design the safety devices and procedures. Several authors have dealt with the safety critical knowledge management in the design phase (refs).

Building: The **SCK** is, for example, the knowledge that will ensure that building procedures and building codes are understood and respected and that the plant will be built to operate safely.

Operation: During operation of a hazardous plant, the **SCK** is the knowledge that will ensure that the plant is operated safely: understanding of the signs, procedures, rules, information on the process but also of the safety devices and procedures that are used to control potential accident scenarios.

Maintenance: There are many examples of wrong operations done in maintenance that were responsible of major accidents. In many cases, the knowledge of the maintenance team was not suitable to interpret the potential consequences of the choices made during the maintenance operation. On the other hand, risk-based maintenance is developing as a means to optimise the maintenance process. Risk-based maintenance relies on the active processing of knowledge on the installation and its equipment, including the use of learning from accidents or incidents.

Decommissioning: Decommissioning is also a critical phase of a plant life. During this phase, operators are faced with aspects of the plant that they didn't have the opportunity to see during the operation. At this stage, generic knowledge and knowledge gained from learning from other's experience are essential.

SAFETY CRITICAL KNOWLEDGE AND SPECIFIC SAFETY MANAGEMENT ACTIVITIES

Within the general life cycle of an industrial plant, some activities have a specific role in the safety management process and are of special interest in terms of knowledge management because of their specific role in the knowledge identification and production process but also because they allow to stress some of the functions that are expected from a safety critical knowledge management system.

EMERGENCY PLANNING AND INTERVENTION

Emergency situations are clearly situations in which safety critical knowledge is mobilised. Emergency rescue teams must have an immediate access to all the information and more generally knowledge useful for understanding the accident and its potential consequences in order to design a safe and efficient intervention strategy. The peculiarity of these situations is the time constraint which prohibits the delivery of a noisy information and imposes that tacit knowledge and personal skills compensate the lack of information.

LEARNING FROM ACCIDENT

Learning from accidents is typically a knowledge management activity. It can take various aspects: in depth analysis of accidents to set up improvements, accident databases describing accident scenarios, analysis of the emergency response of an organisation facing an accident. But exploiting the information contained in accident databases remains a difficult task because of the lack of efficient information retrieval tools. Knowledge management technologies exposed in the following paragraphs can also contribute to improving the learning from accident process.

RISK ASSESSMENT: A KNOWLEDGE INTENSIVE TASK

Risk analysis, and more generally risk assessment, is a knowledge formalisation process in the sense that it consists in extracting tacit knowledge from the participants of a risk analysis work group and turning it into explicit knowledge. Yet to do so, risk analysis also requires that the participants have quite an extensive explicit knowledge both at a specific and generic level. Figure 1 describes the various types of

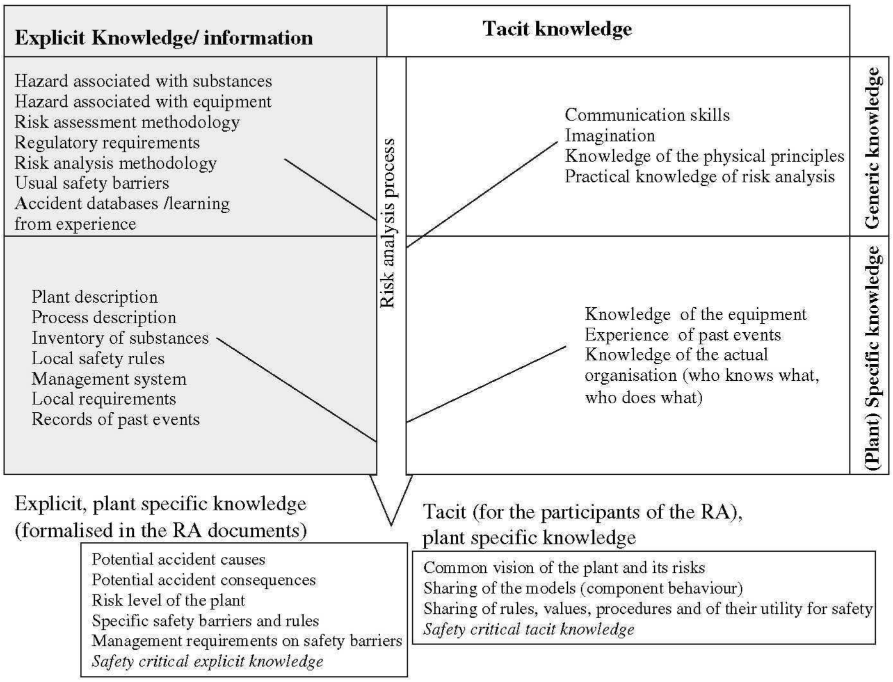

Figure 1. Various types of knowledge involved in the risk analysis process

knowledge involved in the risk analysis process. Projects such as ARAMIS [Salvi, 2006] have also produced large amounts of risk analysis specific knowledge. A first issue is how to make this necessary knowledge available to the actors. This is partly the goal of a tool like PRIMARISK described below.

Another issue is how to insure that risk analysis results will remain useful and known by the safety management actors. Risk analysis is among the best way to produce **SCK**. Far too often, risk analysis remains under exploited once the decisions for which it was done have been taken. At best, it is read by operators or maintenance teams before new decisions are taken. At worst it ends up lost somewhere in the plant. However there should be a means to make risk analysis results easily available as a central piece of the safety management system.

AN EXAMPLE OF GENERIC KNOWLEDGE ACCESS TOOL: PRIMARISK

As described in figure 1, the risk expert uses a large variety of models and data associated to the various steps of risk assessment processes. To make these models, tools and data available to the risk assessment community, INERIS is presently developing the resource platform PRIMARISK® [Debray, 2005]. It is available on INERIS web site since January 2007[2]. The next paragraphs describe the main features of this web platform and present its basic structure in relation with the needs of potential users.

Specific risk assessment processes are defined by the legislation, standards or state of the art. At the end of its development, PRIMARISK will describe several risk assessment processes related to the main activity domains of INERIS. The first to be implemented in PRIMARISK is the safety report of a hazardous industrial plant as it is required by the transposition of the SEVESO II directive. It involves the following steps:

- Description of the plant;
- Identification of the hazardous pieces of equipment;
- Selection of the pertinent equipment;
- Risk analysis;
- Identification of the safety barriers;
- Assessment of the consequences of accidents;
- Definition of the safety control and requirements for the safety management system.

Each of these steps mobilises a specific knowledge. The description of the process is explicit but the understanding of which models, tools and data to use is more of a tacit type. The expertise lies in the ability to use the right model for a given hazardous situation. It lies also in the capacity to understand the results of the process. In PRIMARISK®, each steps is described in terms of objectives. The relevant legislative texts are given together with other reference text, when they exist. Then the tasks are listed. Each of them is described and linked with useful resources and knowledge elements that will ease the risk assessment.

[2]Http://www.ineris.fr/primarisk

The resources can be of three main types:

- Local resources: PRIMARISK lists the elements of information that the person in charge of the risk assessment has to obtain from the plant operator such as the maps or process instrumentation diagrams.
- General resources: These are the resources available elsewhere that the user should consult to obtain useful information. Most of these resources are available online from INERIS or other web sites. Among these are databases, documentation, etc.
- Specific resources available directly from PRIMARISK: These are tools and databases that were developed specially for being made accessible through PRIMARISK. For example, PRIMARSIK supports a series of computer models for the online calculation of effect distances of hazardous phenomena such as BLEVE, Boil-Over and pool fire. Other models are being developed and should constitute progressively a global tool kit for major industrial risk assessment.

Figure 2 shows the general structure of PRIMARISK®. The core system was implemented on a database and establishes the link with classical web pages and more specific online software.

EXAMPLE OF A SPECIFIC KNOWLEDGE MANAGEMENT SYSTEM

Prior to PRIMARISK, which is dedicated mostly to external users, INERIS has set up an internal document management tool called GEIDE. It is the collection of all the documents produced by INERIS personnel. These are of very varied types ranging from reports to short notes or quality management procedures. The primary objective of this system was knowledge capitalisation, aiming at making any knowledge production by INERIS available to INERIS experts. GEIDE is thus a huge document database which uses a Verity K2 search engine. Queries can be formulated in natural language on the full text or on specific meta-data fields.

The difficulty both in PRIMARISK and GEIDE resides in the capacity of a user to formulate a precise query and in the number of documents that can be retrieved from one query. Depending on the quality of this query, the results can be either too scarce or too many. To improve the search efficiency, it is necessary to develop new search tools based on semantic technologies. This is done by developing an ontology of industrial safety and tools to exploit this ontology in PRIMARISK and GEIDE.

DEFINITION OF AN ONTOLOGY OF INDUSTRIAL SAFETY FOR THE IMPROVEMENT OF KNOWLEDGE RETRIEVAL

Ontologies are efficient structures used to formalise the knowledge of a specific domain. An ontology contains a set of concepts of the studied domain organised in a hierarchy of classes and sub-classes along with other relations between them. In practical terms, developing an ontology includes defining classes of concepts, arranging them into a taxonomic (subclass–superclass) hierarchy, defining properties and their facets (constraints). A knowledge base can then be created by defining individual instances of these classes filling in specific property value information and additional property restrictions.

Developing ontologies has many advantages mentioned by N. F. Noy and D. L. McGuinnes, 2001:

- Share a common understanding of the structure of information among people or software agents.
- Enable reuse of domain knowledge.
- Make domain assumptions explicit.

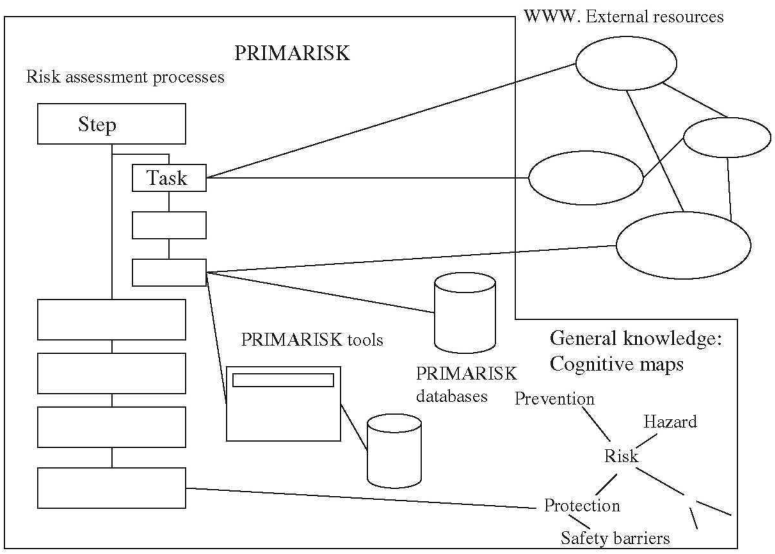

Figure 2. General structure of PRIMARISK

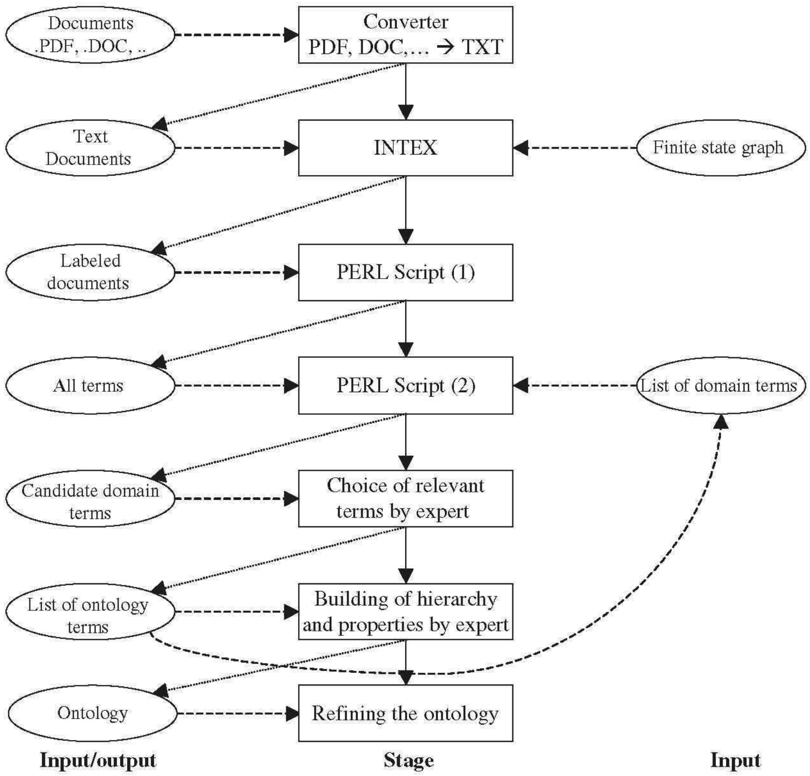

Figure 3. Stages of the ontology development and use process

- Separate domain knowledge from the operational knowledge.
- Analyse domain knowledge.

BUILDING AN ONTOLOGY OF INDUSTRIAL SAFETY

Ontology tools were developed to extract terms from the documents present in PRIMARISK and existing glossaries. Experts were then asked to organise this knowledge into classes and subclasses, defining the properties of classes and their relations. Building the ontology was initiated using the Protégé 3.3 ontology editor and other tools developed specifically [Abou Assali, 2006]. The process is described in Figure 3. A first version of the ontology was built and used as a test support for the elaboration of an information retrieval system described in Figure 4. The evolution of this ontology will continue in the coming years as a central knowledge formalisation process.

CURRENT USE OF THE ONTOLOGY

A simple ontology-based information retrieval system was developed to improve the search capabilities in PRIMARISK and will be soon adapted to the GEIDE system. From a first input of the user, this tool proposes the list of concepts containing at least one of the entered words. The user chooses the concept that suits most his query. Then, a list of related close terms is proposed. A close term is defined as any term having a direct relationship with the initial term. This relation can be an *is_a* relation but also any other type of relation such as the *produces* relation described in Figure 5.

For example, a user entering the keyword "ATEX explosion" will be proposed to refine his query by choosing among "gas explosion" and "dust explosion" but also "overpressure effect" and "thermal effect". This system allows at the same time for a better formulation of the query by the user and offers possibilities of refinement or enrichment of the results. Indeed the user has the choice to limit the search to the specific term of the ontology that best describes his search or to enlarge the results to all the documents linked to this term by a specific relation (close terms).

POTENTIAL USE IN THE FUTURE

This first application of the ontology can be compared with that of thesaurus and structured lists such as the one realised in the S-2-S project [Nomen, 2006]. It is a first step. But the ontology can have many other applications. Its ability to represent a variety of relations between abstract concepts and concrete instances makes it a very powerful tool for information processing and knowledge management. The next step of the research project is the use of an ontology to represent plant specific knowledge (description of equipment, procedures, etc.) and to make the link between this

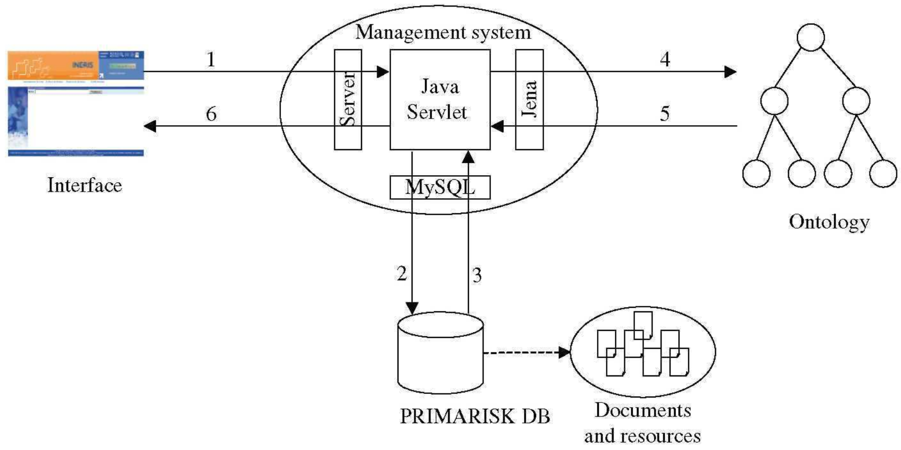

Figure 4. Architecture of the search system in PRIMARISK exploiting the ontology structure

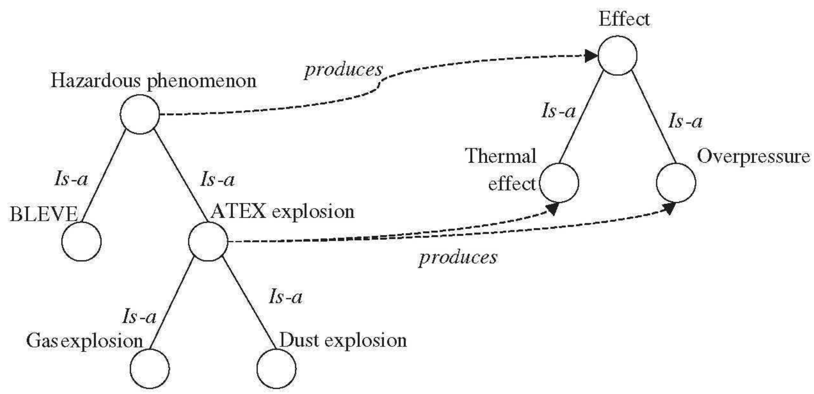

Figure 5. Examples class hierarchy of concepts in the ontology of industrial safety and examples of semantic relation between concepts

ontology and the ontology of industrial safety to index documents and elements of Safety Critical Knowledge. Examples of such approaches for the taking into account of safety requirements in the design and maintenance activities are given by [Bragatto 2006, Ansaldi 2006]. This will constitute a first element of a safety critical knowledge management system. In the future, the ontology will also be used to structure the content of PRIMARISK and GEIDE so that this information can be better accessible and shared with other actors including other risk specialised institutes. Indeed an ontology is not only a set of concepts and relations but also a complete database structure in which the instances of concepts can be compared to database records. The same ontology will thus become the common tool for knowledge formalisation (defining the concepts and relations), information search and retrieval and database structure definition.

CONCLUSION

Through the description of the variety of knowledge involved in various activities and plant life cycle stages, this paper has underlined the critical role of knowledge in the safety management. The concept of **Safety Critical Knowledge** is introduced and the need for a **Safety critical Knowledge** management system are sketched. To answer some of these needs, INERIS has set up a knowledge access tools for external use (PRIMARISK) and an internal knowledge management system (GEIDE). It has also initiated the development of an ontology of industrial safety which will become a basis for knowledge formalisation (defining the concepts and relations), information retrieval and retrieval and database structure definition. This ontology proposes a representation of the main concepts of industrial safety and their relations. It is presently used to improve the document search in PRIMARISK and

GEIDE but will soon provide the base for the definition of a more general Safety Critical Knowledge management system.

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